Variable impedance LED matrix control system for lamps in PV applications

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Abstract.

The interest in LED lighting has been growing recently due to the high efficacy, lifetime and ruggedness that this technology offers. However the key element to guarantee those parameters with these new electronic devices is to keep under control the working temperature of the semiconductor crystal.

This paper proposes a LED lamp design that fulfils the requirements of a PV lighting systems, whose main quality criteria is reliability. It uses directly as a power supply a non-stabilized constant voltage source, as batteries. An electronic control architecture is used to regulate the current applied to the LED matrix according to their temperature and the voltage output value of the batteries with two pulse modulation signals (PWM) signals. The first one connects and disconnects the LEDs to the power supply and the second one connects and disconnects several emitters to the electric circuit changing its overall impedance. A prototype of the LED lamp has been implemented and tested at different temperatures and battery voltages.

1. – Introduction

Light emitting diode (LED) lighting has gone from a promising technology to a real alternative in general lighting [1-2]. The objective of this paper is to improve their reliability and, consequently, their lifetime of the adaptation of LED lighting technology to PV lighting domestic systems.

Catastrophic failures rarely occur in properly biased LEDS. Thus, the lifetime of LED lamps is considered measuring the light output degradation over time. Narendran et al. [3] found that the light output decreases in an exponential manner as the temperature operation of LED increases. Even high quality LED devices with an equal input current of 350 mA, has its lifetime increased a 25% if the junction temperature is reduced from 80ºC to 65ºC.

Currently almost all the LED lamps works using an electronic driver which acts as a current regulated output DC-DC converter. The reliability of these components is also highly dependent on temperature. Therefore, thermal management is the key aspect to guarantee the reliability of LED lamps in PV applications. In this paper, we propose a new LED lamp that can be directly connected to the PV system batteries and implies the employment of one unique electronic control unit based on an intelligent digital microcontroller that uses temperature as feedback information. In this way, its reliability and efficacy are increased, making this LED lamp suitable for stand-alone applications.

2.– LED driving techniques

2.1.– Constant power source based techniques

The illuminance of a high power LED depends on two related factors: the forward current and its junction temperature. The I-V relationship of the LED depends on the LED junction temperature (typically -3.3 mV/ºC) and at a given constant luminance, the power consumption increases with temperature. Thus:

- If a forward CC is applied to the LED, the increase in the junction temperature causes a slight decrease in its voltage drop and in the illumination, creating a natural mechanism of negative feedback.
- If a constant direct voltage is applied to the LED, the same increment in temperature would produce an exponential increase of the forward current and finally a catastrophic failure of the device.

This is the reason why the standard method of driving LEDs is the use for CC sources [4]. However, the usage of these kinds of power supplies on PV autonomous systems has two main drawbacks:

- They avoid fatal breakdowns of the lamp but they do not control the LED temperature, as this depends on the current driving but also on the ambient temperature and the lamp´s heat dissipation capability.
- Batteries of PV stand-alone systems behave as a constant voltage power supply. A CC output needs extra equipment with the consequent increment of cost and loss of efficiency and reliability.

2.2.– LED matrix temperature feedback based technique

Now the working principle is to assure that the temperature inside the LEDs is kept inside the range that guarantees a maximum lifetime. The optimal driving technique would be that which directly uses the PV system battery as a voltage source for driving the LEDs but, somehow, avoids the risk of excessive temperature.

2.2.1.– Constant Voltage PWM regulation based on temperature control.

The proposed control architecture regulates the width of the active pulse of the PWM signal that connects or disconnects the power source with the LED matrix depending on their thermal working condition. It this way, when this temperature overpasses the level that guarantees the expected lifetime, the duty-cycle of the PWM is reduced. This reduces the heat generation as well as the global brightness level of the lamp. This negative feedback compensates the increase of current produced by the raise of temperature inside the LEDs powered with constant voltage.

A power MOSFET interface is all that is necessary to connect the LED matrix with the battery voltage. Its function is to plug or unplug the cathode of the lighting diodes from the power supply depending on the status of the PWM control signal. The switching commutation frequency must be high enough to avoid any flickering of the light that could be perceived by the human eye.

2.2.2. – PWM regulation based on voltage input.

The exponential V-I relationship of a white LED takes the effect that the brightness decreases dramatically when the voltage drops, due to the exponential shape of this curve, making the luminance unsatisfactory. This behaviour also applies to a chain of devices serial connected.

All the last LEDs of the parallel diodes lines can be bridged with a high-power low value resistor with a new MOSFET transistor. This electronic commuter is off in normal operation. However, the control unit may set it on when detects that the voltage supply is less than a previously programmed threshold voltage. The effective impedance of the circuit is modified depending on the resistor value and the PWM signal used to activate this MOSFET so that part of the current flows through the LEDs and the rest trough the resistors. Therefore, the voltage drop at these LEDs is reduced and the voltage at the rest of the matrix is increased and so its brightness.

3. – Practical implementation and evaluation

A test LED lamp prototype has been set up. It contains 28 LEDs manufactured by CREE (model MX-6, intensity bin R2). The LED matrix has 4 strings of 4 LEDs each. The heat aluminium radiator has been designed to work at an ambient temperature of 40 ºC at a duty-cycle of 100 % (nominal conditions) while the LEDs matrix is controlled at around 70 ºC. This ensures a lifetime expectation of over 120.000 hours with a light efficiency of, approximately, 100 lm/W [5]. See figure 1.

The LED matrix includes a second n-channel MOSFET in series with a set of resistors (R). This circuit is in parallel with the four LEDs connected to the negative terminal of the battery. This scheme is designed to take into account that stand alone PV systems have a wide range of voltage supply. For a system of 12V nominal voltage, the voltage supply can range between 10V and 15V.

The control algorithm is based on looking for a target temperature. This value is configured depending on the ambient temperature and the physical installation of the lamp, adequate to the expected lifetime desired. The chip LED temperature has been estimated to be between 3 ºC and 7 ºC above the value measured on the digital sensor placed on the LED´s PCB. A target temperature of 65 ºC, leads to a junction temperature between 68 ºC to 72 ºC on every working situation.

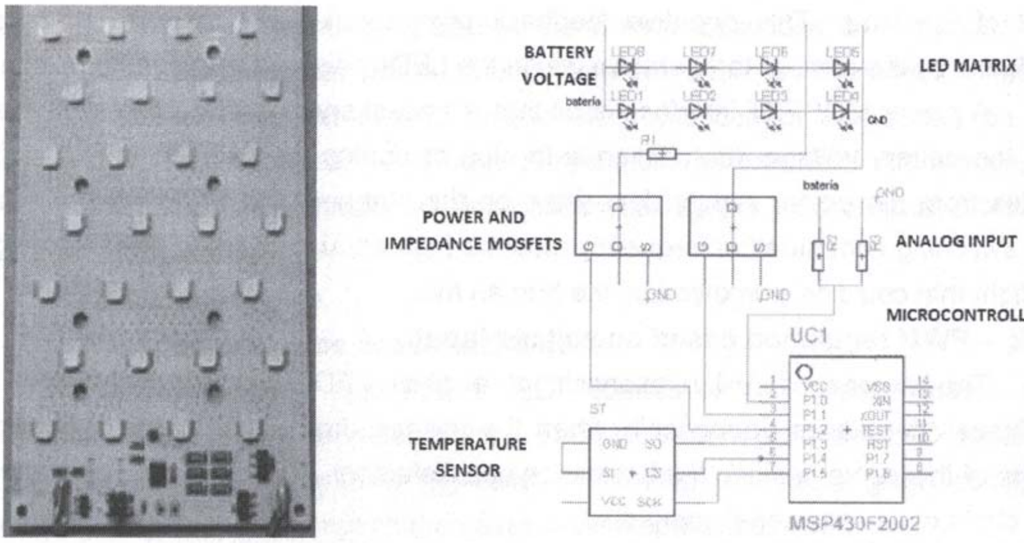

Fig 1. 12 Volt (4 LEDs on each branch) with 2 PWM regulation LED Matrix

The microcontroller does a proportional – integral (PI) control routine based on the difference between the temperature measured and desired, and is implemented by the duty-cycle of the PWM that controls its MOSFET. The frequency is established on 1 KHz. This value is high enough to avoid any flickering on the emitted light and low enough to neglect the switching losses in the MOSFET and EMIF.

The control unit measures the battery voltage and based on a look-up table decides the impedance control MOSFET´s PWM signal. The frequency of this PWM signal is established to 20 KHz. This value is 20 times higher to avoid any interference or accomplishment with the temperature based power control signal. Different working stages depending on the battery voltage are shown on figure 2.

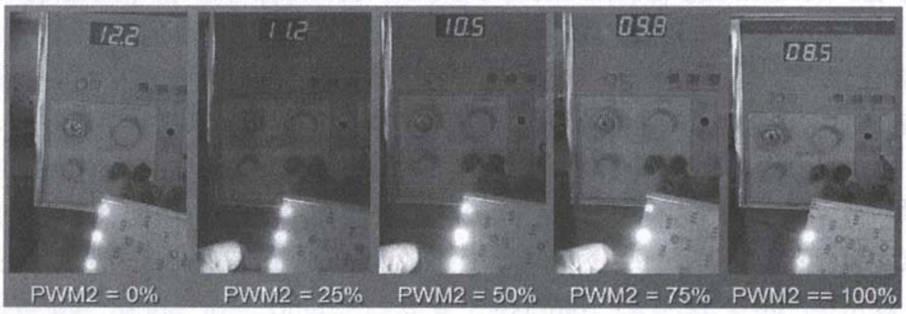

Fig 2. Impedance control PWM and LED matrix brightness

3.2. – Evaluation

The performance of the prototype has been measured inside a thermal isolated camera with temperature control and compared to a similar LED matrix with all the diodes serialized and powered with a 350 mA CC supply. To measure the light emitted we have also placed inside a luxometer sensor at 50 cm. from both lamps.

We have controlled the voltage supply value and the ambient camera temperature and we have measured the temperature of the heat radiators. The lamp performance has been measured using a constant voltage input of 12.6 V. at a 35 ºC ambient temperature. When the radiator temperature reached the stationary status the illuminance, current consumption, and the radiator´s temperature were measured and considered nominal. The cabin´s temperature is established to extreme test values: 10 ºC and 50 ºC, to test the two lamp prototypes. Afterwards the new ED matrix has been exposed to all the possible voltage values of the battery on normal working operation. The test´s results are presented on tables I and II and on figure 3.

This is a good behavior for PV stand-alone systems as the consumption is reduced at low voltage just when the state of charge of is also low, which contributes to a good energy management, while maintaining a good level of illumination. In all the range these levels of efficacy measured mean an increase of performance quality in the current state of the art of PV lighting domestic systems [6-7].

	DC +Tª	CC Driver	DC +Tª	CC Driver	DC +Tª	CC Driver
	Reference					
Room Tª	35ºC	35ºC	50ºC	50ºC	10ºC	10ºC
Lamp Tª	58ºC	59ºC	67ºC	86ºC	31ºC	36ºC
Power Vs. Ref	100%	108%	45%	110%	82%	110%
Iluminance Vs. reference	100%	100%	52%	94%	89%	105%
Efficacy Vs. reference	100%	92%	114%	85%	108%	95%

Table I: Working parameters comparison of LED lamp power systems over different ambient temperatures. (a) Constant voltage supply with temperature feedback (DC+Tª) versus (b) constant current (CC) electronic driver (92% electric efficiency)

	Battery´s maximum: 15 V	Maximum power consumption: 12,6V	Battery´s minimum: 10 V
Control Type	Input power PWM	None	Variable impedance PWM
Power / Nominal Reference	82%	106%	76 %
Illuminance / Nominal Reference	80%	105%	80 %

Table II: control lamp behavior though the range of battery voltages.

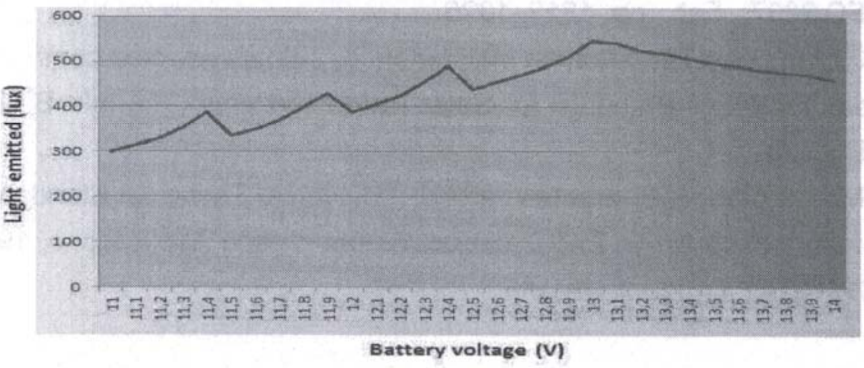

Fig 3. Light emitted versus battery voltage at 40ºC room temperature.

6. – Conclusions

This paper proposes the further development of an electronic control architecture used in LED lamps designed for PV applications. It works without a DC constant current sources and can be directly connected to the batteries of the system, which makes it very easy to adapt to any Solar Home Systems. It integrates an electronic digital control unit with one ultra-low power microcontroller that uses the measure of the battery's voltage and the semiconductor's temperature –measured with a digital sensor within the LED matrix- as feedback control information.

This control unit can modify the current that flows through the LED matrix using several MOSFET transistors as digital commuters operated with PWMs. In this architecture, one LED matrix with many parallel groups of LEDs can be connected directly to a PV system through these transistors. The number of LEDs on each branch depends on their nominal polarization voltage and must be close to the nominal working voltage of the PV system. In this case it is possible to:

A) Reduce the input power applied to the LEDs in order to adapt the lamp to the ambient working conditions (such as high temperatures that will reduce the efficiency and the lifetime expectation or overvoltage from the PV panels)

B) Modify the LED matrix's impedance short circuiting some of the emitters. If the voltage of the batteries falls down, the control achieves that the driven current suffers only a small reduction avoiding big changes in the light emitted.

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